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利用一块相位掩模和两块棱镜改变光纤光栅的写入 Bragg 波长

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摘要:提出一种相位掩模干涉仪用于对光纤光栅写入不同的 Bragg 波长。该系统中,光纤光栅由两块可旋转棱镜所形成的紫外干涉条纹写入,其中相位掩模被用作1级衍射光的分束器。当两块顶角由相位掩模的1级衍射角和棱镜折射率确定的棱镜的底部相互平行放置时,该相位掩模给出了 Bragg 波长的参考值。当 Bragg 波长的频移为1 nm 时,棱镜最大的旋转角为1°,最小的旋转角是2.4′。与 Talbot 干涉仪中平面镜的旋转角23″/nm 相比,该相位干涉仪中棱镜的旋转精度降低了2~3个数量级。该可调谐相位掩模干涉仪仅用一块相位掩模和两块旋转棱镜就可实现写入具有不同 Bragg 波长的光栅,替代了许多具有不同光栅周期的相位掩模。

关 键 词:光纤 Bragg 光栅;Bragg 波长;相位干涉仪;干涉条纹;棱镜
中图分类号:TH741.13;TN253 **文献标识码**:A

Changing written Bragg wavelengths of fiber gratings *via* one phase mask and two prisms

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Abstract: A phase mask interferometer is developed to write gratings with an arbitrary Bragg wavelength. In this system, the gratings are written by the UV interference fringes derived from two rotatable prisms, and the phase mask is used as a beam splitter. Furthermore, when the undersides of two prisms with the vertex angle defined by the ±1 diffraction angles of phase mask and the refactive index of the prism are paraplleI each other, the phase mask initializes the reference quantity of Bragg wavelength. As the shift of Bragg wavelength is 1 nm, the maximum rotation angle of the prism is 1°, and the minimum rotation angle is 2.4′. By contrasting with the rotation angle 23″/nm of the mirror in Talbot interferometer, the rotation precision of the prisms is decreased by two or three orders of magnitude in this phase mask interferometer. Instead of many phase masks with different grating periods, the phase mask interferometer can write grating with the written wavelength of

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1 450 – 1 600 nm *via* a phase mask and two rotatable prisms.

Key words: fiber Bragg grating; Bragg wavelength; phase mask interferometer; interference fringe; prism

1 Introduction

Since the fiber was placed directly behind a phase mask by K. O. Hill *et al.* [1], this method has been used widely for writing fiber Bragg grating. In this scheme, the grating period of phase mask corresponds to an identical inscribed Bragg wavelength. Therefore many methods for changing the written Bragg wavelength are developed[2~6]. One of the most effective methods is the Talbot interferometer technique, which employs one phase mask and two UV-reflected mirrors to spatially modulate the UV writing beam[5,6]. However, the rotation angle of the mirror is 23″/nm in Talbot interferometer, in which it is hard to satisfy the rotation precision.

Basing on above consideration, this paper offers a tunable phase mask interferometer which includes a phase mask and two rotatable prisms to change the written Bragg wavelengths of gratings.

2 Operational principle of a phase mask interferometer

The phase mask interferometer is consisted of a phase mask and two rotatable prisms, and the fibers are placed in near or far field interfering fringes, as shown in Fig. 1. Where a screen is placed in the zero-order block, the residual zero-order light is avoided from the interfering fringes.

With the period Λ_{pm} of the phase mask, the incident light and the diffracted light satisfy the general diffractive equation:

$$\Lambda_{pm} = \frac{\lambda_{UV}}{\sin(\theta/2)}, \qquad (1)$$

where $\theta/2$ is the ±1 order diffracted angles, λ_{UV} is the wavelength of incident light. In this interferometer, the ±1 order diffracted UV beams refracted

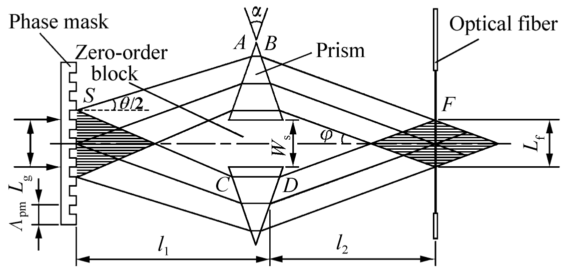

Fig. 1 Schematic diagram of phase mask interferometer with one phase mask and two prisms

twice by two prisms are interfered in fiber. Here, the period of the fiber Bragg grating Λ is given by the mutual angle of two interfering beams [7]:

$$\Lambda = \frac{\lambda_{UV}}{2\sin\varphi}, \qquad (2)$$

In Fig. 2, after the diffractive beam is incident to one of the equiangular planes of prism at the angle of $\varphi = \alpha/2 + \theta/2$, the beams are refracted at the angle of $\alpha/2$:

$$\sin(\phi) = n_s \sin(\alpha/2), \qquad (3)$$

where n_s is the refractive index of UV-transmitted prism with a vertex angle α.

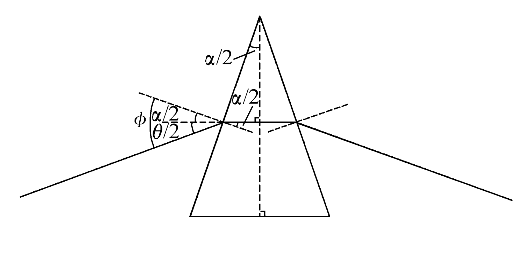

Fig. 2 Vertex angle α defined by ±1 diffraction angles $\theta/2$ derived from phase mask and refractive index n_s of prism

Inserting $\phi = \alpha/2 + \theta/2$ into Eq. (3), the vertex angle of prism can be expressed as:

$$\alpha = 2\arctan\left[\frac{\sin(\theta/2)}{n_s - \cos(\theta/2)}\right], \qquad (4)$$

Then, the once refracted beam in prism is projected to the other equiangular plane at the angle of $\alpha/2$. Refracted from this plane again, the beam emits at the angle of ϕ from the prisms. Finally, the refracted beams are interfered in the fiber at the half angle of $\theta/2$. In Fig. 1, the phase mask is not only used as a beam splitter, but also initializes the reference quantity of Bragg wavelength when the undersides of two prisms are parallel each other. Here, the period of fiber Bragg grating is equal to the half period of phase mask:

$$\Lambda = \frac{\lambda_{UV}}{2\sin(\theta/2)} = \frac{\Lambda_{pm}}{2}, \tag{5}$$

In this scheme, the optical paths of the two interfering beams are symmetrical, and make this interferometer suitable to use with low-spatial-coherence sources. In noncontact writing scheme, the fiber is placed in the far field interfering fringes, where the overlaps of the two interfering beams form a diamond fringe with the maximum length $L_f = L_g$. In Fig. 1, the maximum optical path difference δL_{SF} is the difference between the ± 1 order diffractive light beams derived from the point S, and intersected at the point F,

$$\delta L_{SF} = (L_{SC} + n_s L_{CD} + L_{DF} - (L_{SA} + n_s L_{AB} + L_{BF}), \tag{6}$$

where, L_{SA}, L_{AB}, L_{BF}, L_{SC}, L_{CD}, *and* L_{DF} are the lengths between the corresponding points. According to the geometry of optical path in Fig. 1, Eq. (6) can be simplified as:

$$\delta L_{SF} = 2L_g[n_s\tan(\alpha/2) - \frac{\sin(\alpha/2)}{\cos\phi}], \tag{7}$$

To satisfy the coherence condition, the maximum optical path difference is less than the temporal coherence length:

$$\delta L_{SF} < L_{tc}, \tag{8}$$

where L_{tc} is the temporal coherence length of the laser source in the two-beam interferometer.

The prisms are at halfway between the phase mask and the fiber. In Fig. 1, the distances between the prism to the phase mask, and to the fiber can be expressed as:

$$\begin{cases} l_1 = \dfrac{W_s + L_s\cos(\theta/2)}{2}\cot(\theta/2) + L_s\cos(\alpha/2) \\ l_2 = \dfrac{W_s + L_s\cos(\theta/2)}{2}\cot(\theta/2) \end{cases}, \tag{9}$$

where, l_1 is the distance between the prism to phase mask, l_2 is the distance between the prism to the fiber, and W_s is the transverse gap between the two prisms. For considering the zero-order block, the gap W_s between two prisms can be defined as,

$$W_s > L_g, \tag{10}$$

Because the beam is incident to one of the equiangular planes of prism at the angle of ϕ, the effect length L_g is limited by the length L_s of the equiangular plane as:

$$L_g < L_s\frac{\cos(\phi)}{\cos(\theta/2)}, \tag{11}$$

3　Changing written Bragg wavelength by rotating two prisms

In this scheme, the rotation of prisms plays a critical role for changing the written Bragg wavelength, as shown in Fig. 3. The broken and solid lines indicate the optical paths before and after rotating the prisms at the angle of δ, respectively.

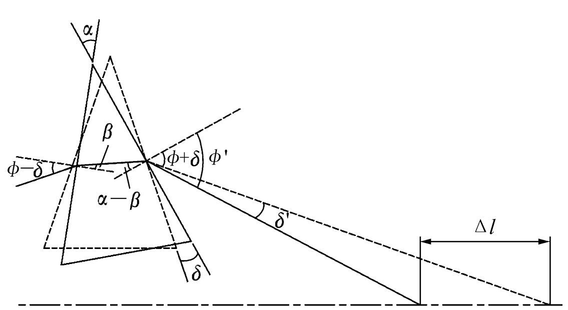

Fig. 3　As the prism is rotated at the angle of δ, the direction of beam is changed at the angle of δ', and the intersection between two beams is moved at the distance of Δl

The ± 1 order diffractive beams derived from the phase mask are incident to one of the equiangular planes of prism at the angle of ϕ. As the prisms are rotated at the angle of δ, the incident angle is to $\phi-\delta$. According to the refractive law, the refractive angle β is formulated by:

$$\beta = \arcsin\left[\frac{\sin(\phi-\delta)}{n_s}\right], \qquad (12)$$

where, n_s is the refractive index of the UV-transmitting prism. Then, the once refracted beam in prism is incident to the other equiangular plane at the angle of $\alpha-\beta$. Finally, the angle ϕ' at which the beam is refracted is:

$$\phi' = \arcsin[n_s \sin(\alpha-\beta)], \qquad (13)$$

and the written angle change δ' is given by

$$\delta' = \phi' - (\phi+\delta). \qquad (14)$$

Thus, instead of φ in Eq. (2), the period of the fiber Bragg grating can be rewritten as

$$\Lambda = \frac{\lambda_{UV}}{2\sin(\theta/2+\delta')}. \qquad (15)$$

Given the Bragg condition, the Bragg resonance wavelength can be represented in terms of the UV writing wavelength and the half angle $\varphi=\theta/2+\delta'$ between interesting UV beams as

$$\lambda_B = 2n_{eff}\Lambda = \frac{n_{eff}\lambda_{UV}}{\sin(\theta/2+\delta')}. \qquad (16)$$

where, n_{eff} is the effective core index of the fiber.

For photo-writing in the diamond bridge of the interfering fringes, the fiber is moved with the maximum interfering length:

$$\Delta l = \frac{W_s + L_s\cos(\theta/2)}{2}\cdot [\cot(\theta/2+\delta') - \cot(\theta/2)]. \qquad (17)$$

In this phase mask interferometer, the grating period of phase mask is $\Lambda_{pm}=1\ 084$ nm, the wavelength of UV is $\lambda_{UV}=248$ nm. Using Eq. (1), the diffractive angle of ±1 order diffraction light $\theta/2$ is 13.225°. Because the refractive index of deep ultraviolet fused silica prism is $n_s=1.55$ at the wavelength of 248 nm[8], the vertex angle of prism is $\alpha=43.289°$ derived from Eq. (4), and the incident angle ϕ is $\alpha/2+\theta/2=34.870°$.

The coherence length of typical excimer laser is about fraction of one mm, even though the EX10BM laser (GAM LASER, Inc., USA) offers a temporal coherence length of $L_{tc}=5$ mm. In order to satisfy the coherence condition of Eq. (8), one can have the maximum optical path difference as $\delta L_{SF}=5$ mm. According to Eq. (7), the effect length of phase mask is limited to $L_g=15$ mm. Then, the length of the equiangular plane is $L_s>18$ mm from Eq. (11).

In the core of optical fiber, the effective refractive index is $n_{eff}=1.46$. In Fig. 4, we present the curve of the Bragg wavelength λ_B as a function of the rotation δ of prisms from Eq. (16).

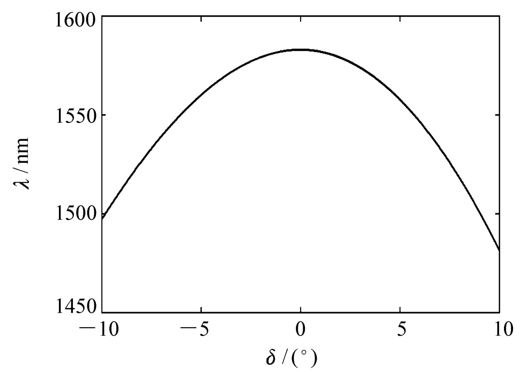

Fig. 4 Relation of Bragg wavelength with rotation angle of prism

To satisfy the size of the refracted plane in Eq. (11) and the size of the mechanical setup, the length of the equiangular plane is $L_s=30$ mm. According to Eq. (10), the length of gap between the two prisms is $W_s=30$ mm. As a result in Eq. (9), the longitudinal distance between prism and phase mask is $l_1=154$ mm, and the longitudinal distance between prism and fiber is $l_2=126$ mm. Fig. 5 shows the shift Δl of the maximum interfering fringe as a fuction of the rotation δ of the prism by Eq. (17).

It is worthwile to point out that the change of the written Bragg wavelength depends on the mutual angle of two prisms. As the angle of prism is rotated from 0° to 10° or to −10°, the Bragg wavelength is 1 582.7−1 481.5 nm or 1 582.7−1 496.7 nm in

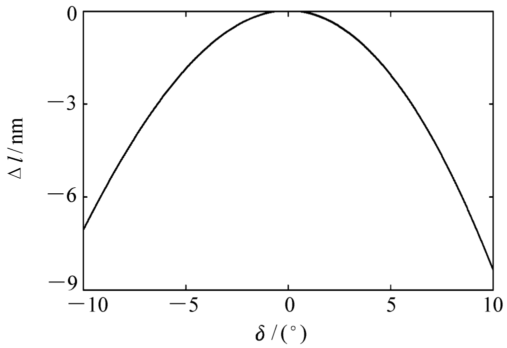

Fig. 5　Position of maximum interfering length shifted by rotation angle of prism

Fig. 4, and the shift of the maximum interfering fringe is 0 – 8. 3 mm or 0 – 7. 1 mm in Fig. 5. As the shift of Bragg wavelength is 1 nm, the maximum rotation angle of the prism in this interferometer is 1°, or the minimum rotation angle is 2. 4′. By contrasting with the rotation angle 23″/nm of the mirror in Talbot interferometer[5, 6], the rotation precision of the prism is decreased by two or three orders of magnitude in this phase mask.

4　Conclusions

The fiber Bragg grating is written by the 248 nm UV interference fringes derived from the prisms, where the phase mask is used as a beam splitter of ±1 order diffraction lights. The variation of written Bragg wavelength is depended on the mutual angle between two writing beams, which can be changed by rotating the prisms. At the same time, the fiber is moved with the diamond bridge of the interfering fringes. It is noteworthy that the rotation precision of the prisms in the phase mask interferometer is lower two or three orders of magnitude than that of the mirrors in Talbot interferometer. By using only a phase mask and two rotatable prisms, the phase mask interferometer can write grating with the written wavelength of 1 450 ~ 1 600 nm.

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